ation," by C. G. Abbott and F. E. Fowle, Jr. Notes: "Activity in Magnetic Work"; "Personalia." Abstracts and Reviews: W. van Bemmelen on "Registration of Earth-currents at Batavia," by L. Steiner; Cirera et Barcells on "Activité solaire et les perturbations magnétiques," by J. A. Fleming; Meyermann on "Korrektion der Reduktionsconstanten eines magnetischen Theodoliten," by J. A. Fleming. List of Recent Publications.

THE LIQUEFACTION OF HELIUM

Information communicated by Sir James Dewar to the London *Times* from Professor Kamerlingh Onnes, of Leiden, shows that helium is a liquid having a boiling point of 4.3 degrees absolute, which is not solid when exhausted to a pressure of ten millimeters of mercury, at which pressure the temperature must have been reduced to within three degrees of the absolute zero—*i. e.,* about one fourth of the temperature of hydrogen in corresponding conditions, as that again is about one fourth of the corresponding nitrogen temperature. If we could obtain another similar drop by the discovery of a gas still more volatile than helium we should have a liquid boiling about one degree above the absolute zero. The *Times* also gives a few notes upon the steps by which the liquefaction of helium has been reached. In 1895, by the application of the method of sudden expansion from high compression, Olscevski, starting from the temperature of exhausted air, failed to get any appearance of liquefaction. In 1901, Dewar, in the Bakerian lecture, described his repetition of that experiment, using liquid hydrogen under exhaustion instead of liquid air, again without obtaining any trace of condensation. Reasoning from the analogy of his experiments on the liquefaction of hydrogen, he showed that by regenerative cooling starting from the temperature of liquid hydrogen, we might expect to liquefy a gas whose boiling point might be as low as four or five degrees absolute. In his presidential address to the British Association in the following year he gave reasons for placing the boiling point of helium at that figure, showing at the same time how great are the experimental difficulties of getting within five degrees of absolute zero. In 1905 Olscevski repeated Dewar's experiment of 1901, using higher pressures, and reached the conclusion that the boiling point of helium must be below two degrees absolute, and that after all the gas might be permanent. The same experiment was repeated early in 1908 by Professor Onnes with a much larger quantity of helium than had previously been available, and he at first thought he had obtained solid helium, but found that the appearance was due to impurity in the gas. Dewar again repeated the experiment by circulating helium in a regenerative apparatus, but though he got cooling, he was baffled by the inadequacy of his supply of helium to maintain the cooling process sufficiently long to reach liquefaction. At last, by the experiment of July 10, Professor Onnes has definitely settled the matter. As new and richer sources of helium have been discovered, and its separation has been enormously facilitated by Dewar's charcoal method, it is possible that helium may become sufficiently abundant in cryological laboratories to be used as liquid hydrogen is now used in physical research.

SPECIAL ARTICLES

ELECTROMAGNETIC MASS

The variations of meaning attached to d'Alembert's principle, that depend upon what we may call the genesis of the terms involved in its expression, has been insisted upon in a previous article.[1] We find a similar double chance open for instructive interpretation in many other equations of theoretical physics, among which we now select that important result in hydrodynamics which may be regarded as furnishing the original suggestion of "electromagnetic mass." For a solid of mass m moving in the line X through an ideal liquid free from boundary conditions, the familiar power equation is

$$Xu = d/dt\left(\tfrac{1}{2}mu^2 + \tfrac{1}{2}m_1u^2\right). \qquad (1)$$

Here X denotes the aggregate of force *external to the system* consisting of m and the

[1] Science, Vol. XXVII., p. 154.

liquid, and acting on m. The term $\frac{1}{2}m_1u^2$, then, is seen to express, in the first introduction of it, the kinetic energy associated with the liquid as a necessary consequence of moving m through it. The ratio of m_1 to m is calculable for various special assumptions.[2] Executing the differentiation with m_1 constant, gives directly

$$X = (m + m_1)\, du/dt. \qquad (2)$$

If we accept this as an "equation of motion," just as it stands, and in the strict sense of d'Alembert, it is obviously not such for m alone, but for that mass plus liquid of constant volume, it is true, but of varying identity. That feature of elusiveness in the mass denoted by m_1 has undoubtedly favored the interpretation of the parenthesis as representing the "effective mass" of m under the conditions, among which must be included that X does not really comprise the total of external force acting on m, in conformity with the suppositions underlying equation (1). The completed equation of motion for m, in which any resistance R—frictional or not—offered by liquid must appear, is

$$X - R = m\, du/dt. \qquad (3)$$

Since $R = m_1\, du/dt$, therefore, because du/dt denotes the actual acceleration in both cases, we have before us another instance of change in reading, from mass-term to force-term, by transposing in the equation. And, from the point of view of equation (3), the power equation (1) can be adapted to the mass m exclusively, by placing $-\frac{1}{2}m_1u^2$ in the first member, as the negative work of the force R. As noted in connection with d'Alembert's principle, each view is justified so long as the proper context is retained, and we do not lose sight of the mental device that harmonizes them. A complete presentation includes both views, and does not overlook, either, the possibility of like alternative statement applying to any equation of motion with corresponding artificial basis. For example, if a mass m is acted upon by forces X_1 and X_2 that would produce separately accelerations a_1 and a_2, it is mathematically correct to write either form:

$$X_1 + X_2 = ma; \quad X_1 = (m - m_1)\, a; \qquad (4)$$

if $a = a_1 + a_2$ is the actual acceleration for the reference system used, and $m_1 = m\, a_2/a$. The "effective mass" of m when the force X_2 is ignored (or unrevealed by first analysis of the phenomena), would be greater or less than m according to the sign of a_2 determined by X_2. The fiction indicated here would serve no useful purpose in many classes of problems, but it offers a certain convenience in treating motions of bodies through media. The effect due to inertia of the medium, or its equivalent, finds adequate recognition by abolishing the medium, and at the same time adding to the inertia of the immersed body. The somewhat vaguely dispersed quality of the medium finds definite location in the bulk of the body.

Wherever the circumstances are thus thoroughly understood, the matter of choice in presentation is controlled completely by our preference; it is enough that the equivalence of two such modes of statement really covers the points aimed at, the confessed fiction being ranged with others like it in mathematical physics. But it is clear that different types of the external agencies called forces lend themselves to calculation as pseudo-inertia of the moving body itself with greater or less facility, the change of front being easiest when a resistance is involved whose magnitude is proportional to the acceleration of the body, as in the well-known hydrodynamical case cited above. Another side of these differences in the mathematical situation is the possibility that they afford for making conditions of unascertained physical nature reveal themselves experimentally as arising from force rather than from real inertia. Thus a resistance proportional to displacement might be identified by adjustment to equilibrium, as in stretching a spring, or charging a condenser; "terminal velocity" is characteristic of other forms of resistance, which prove to be proportional to various powers of speed. This second group includes the obstructive electromotive force of conductors to the passage of current through them, beside the more visible instances of such action. But a resistance pro-

[2] See for example, Lamb, "Hydrodynamics," p. 85, p. 130.

portional to acceleration would evade detection by methods of this kind, since it influences the motion of a body just like a mass measured numerically by the proportional factor. Considered as mass-term or force-term, the sign is reversed as required, and accurate balance with other impressed forces is never brought about. The acceleration that would be produced otherwise is reduced, but steady conditions enter at a finite value of actual acceleration. Supposing, however, that the density of the body falls off, and the "ballast" of real mass is thus diminished, equation (3) approaches a limit $X - R = 0$. And if the proportional factor m_1 of equation (2) be now increased, the acceleration corresponding to equality of X and R will grow less. Equilibrium of the body m can be approached asymptotically, therefore, somewhat as in the case of resistance (proportional to speed) due to eddy currents set up by motion in a magnetic field. For the hydrodynamic problem, the limiting condition $X - R = 0$ would correspond to a rigid massless shell forced through the liquid. The energy supplied would go directly into the latter, the shell transmitting the force X applied to it, undiminished by any distribution throughout its own volume. It is interesting to compare this with the application of the "equilibrium theory" to problems in acoustics.

Every essential aspect of the ideas connected with the equation of motion and the forms derived from it by transposition of terms is found repeated in the parallel electrical statement. The more fundamental form, for a circuit with impressed electromotive force, resistance, capacity and self-induction, is, with obvious notation,

$$E - E_c - IR = L\,dI/dt. \qquad (5)$$

Equation (5) is immediately consistent with the scheme devised by Newton and d'Alembert for the dual measure of forces, in terms of the favoring and hindering agencies themselves on the one hand, and their net result on the other. The former arise externally to the system moved, and the latter affords a mode of calculation in which no exciting stimulus appears directly. The recognition of the coefficient L as "electric inertia" is well rooted; and the proper sense in which the terms of the first member are all "external" is seen readily enough, even in its application to IR, though obscured here, to a certain extent, by the habitual elementary expression of Ohm's law in the form $E = IR$, without explicit recognition of it as involving terminal velocity and equilibrium. It is further apparent how the equation

$$[E - E_c - IR] - [L\,dI/dt] = 0 \qquad (6)$$

presents the idea of d'Alembert's principle, with considerations parallel in detail to those governing its use elsewhere. The proper establishment of these particular analogies is far-reaching enough to excuse their discussion with so much elaboration of emphasis on exceedingly simple conceptions. But there are some indications that original meanings here have become a little incrusted with the formalism of mathematics. A deliberate effort to restore them is not superfluous, if there is any habit of indifference toward fictitious forms of statement to be checked. However harmless such habits may be on familiar ground, they must tend to magnify the difficulties inseparable from attempts to explore and subdue new territory; and, on the other hand, the slightest improvement in giving natural and direct expression to essential phenomena is likely to find quick reward in more rapid advance or deeper insight. At this junction-point of the older mechanics with the modern dynamical treatment of electricity, the transfer of methods from one line of thought to the other calls especially for all precision of ideas that is possible, in view of the inevitable margin of vagueness associated with equations that have been generalized and extended so far beyond their first application.

With the introduction of electrons, an added element of definiteness is infused into electric inertia, and the new suggestion reacts also upon the finality of previous conceptions regarding all mass. We are asked to entertain the possibility that mass is everywhere expressible quantitatively in electromagnetic terms; and to acknowledge as an illusion any former conviction that mass is necessarily

constant. Until now, mass has been attributed to a body in the full sense of locating the mass entirely within the volume of the body, and measuring it by means of phenomena exhibited there. The essential property of mass may be put as its power to store energy in the kinetic form, receiving and retaining the energy passively; that is, acquiring and losing it only under the control of external influence. If we distinguish between "real mass" and "effective mass" in ordinary mechanics, they have in common the passive storage of kinetic energy, definite in amount for a given value of speed; but in using the latter, we assign to the body a certain amount of kinetic energy that is in fact not stored there. This part of the energy is obtainable *through* the body, perhaps, but not precisely *from* it. It happens that the effective mass is constant, under the conditions supposed to govern equations (2) and (3); but that type of supposition does not limit the entire range of the conception. This is evident from equation (4) in which m_1 may be variable. Neither is it essential, when we enter the field of generalized dynamics, that the storage of energy connected with inertia is demonstrably of a nature that would be described accurately as kinetic. The energy must indeed be stored; that is, be conservatively regainable; and this storage must be of passive character in the sense explained above —not accompanied by anything corresponding to resilience, nor automatically convertible like potential energy. These two conditions are sufficient as well as necessary; and the storage of energy ascribed to electromagnetic mass being in fact parallel with kinetic energy to this necessary extent, only one vital inquiry remains. This is concerned with what we may call the *location* of the energy. The generalized inertia will be effective rather than real, in proportion as the energy absorbed is not all stored in the body to which it is assigned conventionally; but is distributed throughout some region—or field—surrounding that body. And it is not excluded, as a limit, that the fraction of the total energy to be found within the boundary of the body itself is a negligible part of the whole.

It is of course nothing more than a commonplace to remark that the energy here in question, in the case of an ordinary electric circuit, is dispersed through a field, though the inertia is spoken of figuratively in association with the conducting track. It is also true that the factor L in equation (5) may be variable. But the electromagnetic theory of electrons is built on models supplied by finite circuits; and the more novel aspects of that theory modify nothing that is for our present purpose essential. Without going further into detail, it is sufficiently evident that the mass of an electron is "effective"; part of it, or perhaps all, attaching really to the electron's own magnetic field—of indefinite extent—though attributed to the diminutive bulk of the electron itself. In writing out dynamical equations for application to electrons, therefore, the inertia belonging to the region outside the boundary of an electron will register its influence on the equation of motion for the electron itself in a force-term, according to the general scheme of equation (4), the electron being the channel for transmission of energy to or from the medium. And if it should be finally established that the inertia of the electron proper is negligible or zero, the transmission would then be of perfect efficiency, corresponding to the condition $X = R$ in the text above. And on that supposition, again speaking of the equation of motion for the electron itself, the application of d'Alembert's principle becomes merely formal, since the terms corresponding to "forces of inertia" have vanished, leaving a zero of force in the first instance, instead of a zero resulting from the introduction of an equilibrant. The term R may indeed be read as a "kinetic reaction," but in a modified sense; it is no longer a reaction excited immediately in the electron by whatever applies the force X, but is the reaction of the medium against the attempt to move the electron according to certain laws. The term R may be more or less approximately proportional to the acceleration of the electron; and differently proportional for different types of acceleration. Hence arises the idea that the electromagnetic mass of an electron is not constant.

The consideration that saves the situation is that the entire effective inertia, no matter what may be its source, and where it may be located, is, as a fact, included in the calculations when mass, momentum, kinetic energy, etc., are regarded as attaching to the electron. This process of expression becomes feasible in terms that involve a physical property of the electron itself (its electric charge) and its kinematical elements (acceleration, velocity, etc.); so that to this extent the parallel is preserved with the mass-factor and the kinematical factors of ordinary mechanics. But it may be well, at intervals, while we take advantage of the undoubted convenience in these methods of presentation, to remind ourselves of their artificial nature, and then to employ their fictions consciously.

Should the suggestion prove true that all mass is an electromagnetic phenomenon, we shall be brought to confess that we have been using some fictions unconsciously; for example, in attributing kinetic energy to a mere cannon-ball which is more nearly a clearing-house for energies spread through cubic kilometers of medium. This would add only one item to a list already long enough, where the result of completer analysis is to substitute a complex process for the superficial and simple one. The tendency to identify quantities of energy with limited volumes of "bodies" seems strong enough to carry a good load of artificial convention. Witness potential energy, entropy, specific heat for constant pressure.

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THE THIRTY-EIGHTH GENERAL MEETING OF THE AMERICAN CHEMICAL SOCIETY

I.

The thirty-eighth general meeting of the American Chemical Society was held at New Haven during June 30, July 1 and 2, in North Sheffield Hall, of Sheffield Scientific School, Yale University. President Hadley welcomed the visiting members and extended the buildings and accessories for their use and general convenience.

On Tuesday and Thursday afternoons, invitations were extended to the chemists to visit the rubber Works of L. Candee & Co., in New Haven, and the works of the New Haven Gas Light Co. Wednesday afternoon a special excursion was made to Ansonia to visit the works of the Ansonia Brass and Copper Company and the Coe Brass Manufacturing Company; at all of these places the visitors were courteously received and shown through the works in a very thorough and painstaking manner.

On Tuesday evening the local members of the society extended a complimentary smoker to the visitors at the Graduate Club House. On Wednesday a subscription shore dinner was given at the "Momanguin" on the east shore. Many of the visitors made use of the excellent salt-water bathing facilities at this place.

The attendance at this meeting was about 250. Greetings were received from Arrhenius, Emil Fischer, Roscoe, Ramsay, Van't Hoff, Julius Thomsen, Lunge and von Baeyer. A paper on "Agglutination and Coagulation" was presented by Savante Arrhenius, of Nobel Institute, Stockholm, and two papers were presented by Emil Fischer, one on "Polypeptides" and one on "Micropolarization."

The following addresses were given before the general assembly:

A. L. Winton, "Official Inspection of Commodities."

Philip E. Browning, "The Increasing Importance of the Rarer Elements."

Wm. D. Richardson, "The Analyst, the Chemist and the Chemical Engineer."

Thos. B. Osborne, "Our Present Knowledge of Plant Proteins."

Frank K. Cameron, "Some Applications of Physical Chemistry."

W. A. Noyes, "Chemical Publications in America in Relation to Chemical Industry."

Wm. Walker, "The Electrolytic Corrosion of Iron as Applied to the Protection of Steam Boilers."

W. E. Whitney, "The Research Chemist."

Wm. McPherson, "A Discussion of Some of the Methods used in Determining the Structure of Organic Compounds."

The following papers were read before the sections:

AGRICULTURAL AND FOOD CHEMISTRY

A. L. Winton, *Chairman*

The Determination of Cottonseed Hulls in Cottonseed Meal: G. S. Fraps.

The method consist of boiling two grams of the material, after extraction with ether, with 200 c.c.